UNITED STATES PATENT APPLICATION

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FOR

ETHYLENEOXIDE-SILANE AND BRIDGED SILANE PRECURSORS FOR FORMING LOW K FILMS

ETHYLENEOXIDE-SILANE AND BRIDGED SILANE PRECURSORS FOR FORMING LOW K FILMS

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to low dielectric constant films, and to precursors and methods useful in making such films.

Description of the Related Art

[0002] As semiconductor devices are scaled to higher processor speeds and smaller, denser structures, there is an increasing need to reduce resistance-capacitance (RC) delays present in interconnect wiring. Since the dielectric constant k is proportional to capacitance (C), scaling relationships require reductions in k values of the dielectric material. In addition to the requirement of low k values, reliability issues require that the dielectric material have a high degree of mechanical strength. Currently available dielectric films have low mechanical strength as k values decrease.

[0003] Among the various materials that are currently available for forming low k films, 1,3,5,7-tetramethylcyclotetrasiloxane (TMCTS) is a widely studied precursor for deposition of low k thin films used as interlayer dielectrics in integrated circuitry. Dielectric films formed from TMCTS typically have k values in a range of from about

2.6 to about 3.0, but lack sufficient hardness for large-scale integration. For next generation very large-scale integration (VLSI) devices, dielectrics will be required that have a dielectric constant k below 2.5 with hardness greater than about 1 gigaPascal (gPa).

[0004] Accordingly, the art continues to seek improvements in dielectric materials, in the quest for dielectrics having both high mechanical strength and low k value.

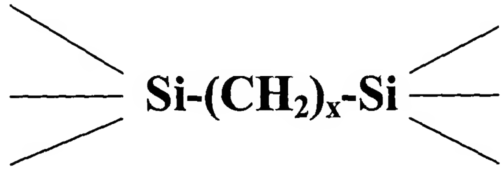
SUMMARY OF THE INVENTION

[0005] The present invention relates generally to low dielectric constant films, and to precursors and methods useful in making such films, e.g., for the manufacture of semiconductor devices and products.

[0006] In one aspect, the invention relates to an organosilicon precursor for vapor deposition, e.g., low pressure (< 100 Torr), plasma-enhanced chemical vapor deposition (PECVD) of a low k, high strength dielectric film, wherein the precursor comprises at least one of:

(i) silicon-pendant oxiranyl functionality; and

(ii) a disilyl moiety of the formula



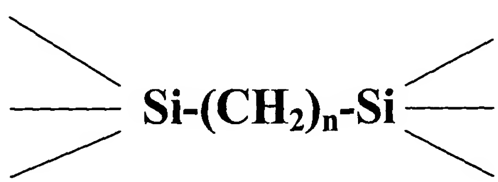
wherein x is an integer having a value of from 0 to 4 inclusive.

[0007] In another aspect, the invention relates to an organosilicon precursor composition for vapor deposition of a low k, high strength dielectric film, wherein the composition comprises:

(A) an organosilicon precursor comprising at least one of:

(i) silicon-pendant oxiranyl functionality; and

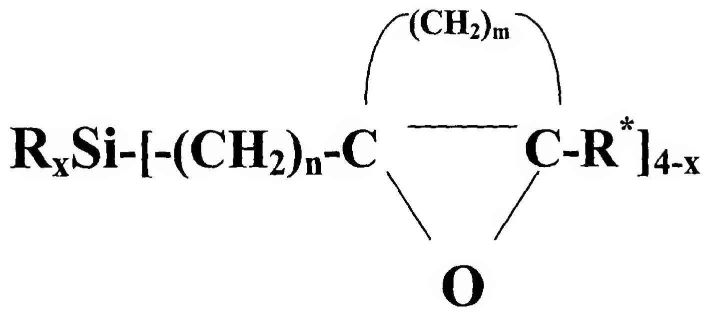
(ii) a disilyl moiety of the formula



wherein x is an integer having a value of from 0 to 4 inclusive; and

(B) a porogen.

[0008] Another aspect of the invention relates to a method of forming an oxiranylsilane compound of formula (I):



(I)

wherein:

m is an integer having a value of 0 to 6, inclusive;

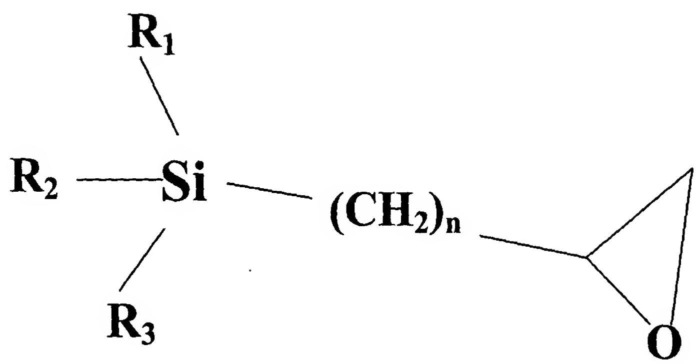
n is 0 or 1;

x is an integer having a value of 0 to 3, inclusive; and

each R and R^* can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl,

such method comprising oxidizing a corresponding vinylsilane or allylsilane compound.

[0009] In one preferred aspect, the oxiranylsilane compound has the formula (II) set out below:



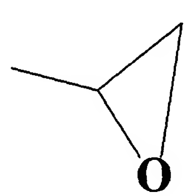
(II)

wherein:

each of R_1, R_2 and R_3 can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl; and

n is 0 or 1;

with the proviso that if n = 1, then one of R_1, R_2 and R_3 alternatively can be an oxiranyl functionality:



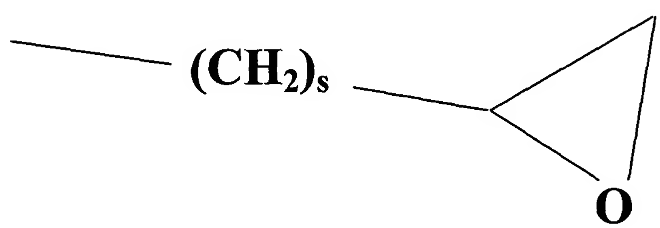
(sometimes hereinafter referred to as ethyleneoxide functionality).

[0010] Yet another aspect of the invention relates to a method of synthesizing a bridged disilane compound of formula (III):

$$R^4R^5R^6Si\text{-}(CH_2)_y\text{-}SiR^7R^8R^9 \qquad \text{(III)}$$

wherein:

each of R^4, R^5, R^6, R^7, R^8 and R^9 can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxyl, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, C_3-C_6 allyl, and oxiranylalkylene of formula (IV)



(IV)

wherein s is 0 or 1; and

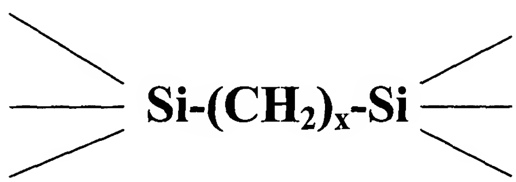
y is an integer having a value of from 0 to 4 inclusive,

such method comprising derivatization of a corresponding bridged chlorosilane.

[0011] In a further aspect, the invention relates to a method of forming a low k, high strength dielectric film on a substrate, comprising vapor depositing said film on the substrate from a precursor comprising at least one of:

(i) silicon-pendant oxiranyl functionality; and

(ii) a disilyl moiety of the formula



wherein x is an integer having a value of from 0 to 4 inclusive.

[0012] Other aspects, features and advantages of the invention will be more fully apparent from the ensuing disclosure and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a graph of FTIR transmission spectra of a film deposited from TMCTS and a film deposited from $Me(EtO_2)SiCHCH_2O$ under low oxygen activity deposition conditions.

[0014] FIG. 2 is a plot of deposition rate, in Angstroms per minute, as a function of measured radio frequency power, in watts, for each of $Me(EtO_2)SiCHCH_2O$ (denoted in the graph as DEOMORS), tetramethylcyclotetrasiloxane (denoted in the graph as

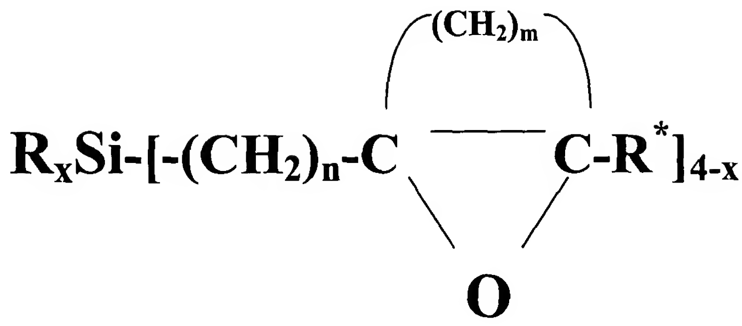
TMCTS), and tetraethylorthosilicate (denoted in the graph as TEOS), each utilized in the deposition process in combination with a same porogen under similar conditions.

DETAILED DESCRIPTION OF THE INVENTION, AND PREFERRED EMBODIMENTS THEREOF

[0015] The present invention contemplates a new class of precursor compounds that are useful in forming low k films having superior mechanical strength characteristics.

[0016] The precursor compounds of the invention in a first general category are organosilicon source reagents including silicon-pendant oxiranyl functionality. The organosilicon source reagents include monosilicon-containing compounds as well as polysilicon-containing compounds, e.g., disilanes, disilylalkyl compounds, disiloxanes and cyclosiloxanes. The number of oxiranyl functional groups in the molecule can be selectively adjusted along with other R and OR groups to optimize the behavior of the precursor molecule for a specific film-forming application, e.g., a low-pressure plasma chemical vapor deposition (CVD) process, and the molecule can include H groups in combination with oxiranyl, methyl, methoxide, and other functionality. Cross-linked silyl structures (having an Si-C-Si moiety) can also be employed in the organosilicon precursors of the invention.

[0017] One general class of compounds of the invention has the formula (I):



(I)

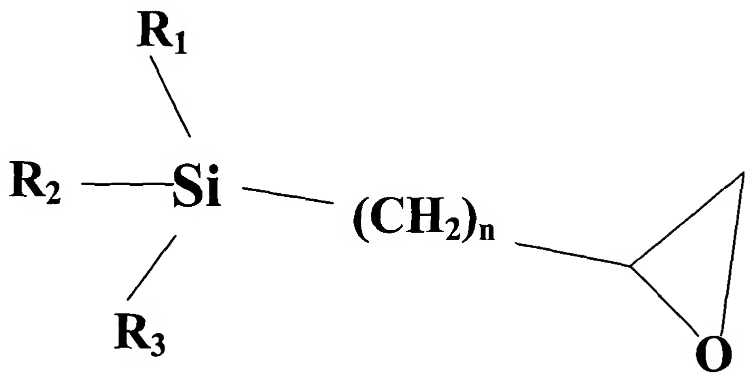
wherein:

m is an integer having a value of 0 to 6, inclusive;

x is an integer having a value of 0 to 3, inclusive; and

each R and R^* can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl.

[0018] Within the foregoing general formula (I), one sub-class of oxiranylsilane compounds of the invention has the formula (II):



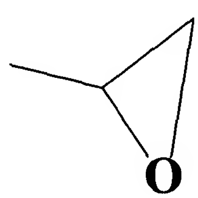
(II)

wherein:

each of R_1, R_2 and R_3 can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl; and

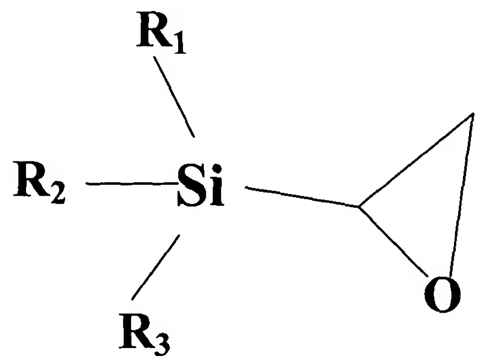
n is 0 or 1;

with the proviso that if n = 1, then one of R_1, R_2 and R_3 alternatively can be



an oxiranyl functionality.

[0019] Within the foregoing general formula (I), another sub-class of silyloxirane compounds of the invention has the formula (V):

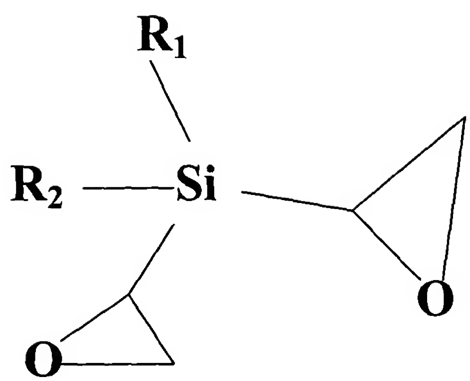


(V)

wherein:

each of R_1, R_2 and R_3 is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl.

[0020] Yet another sub-class of silyloxirane compounds within the general formula set out below has the formula (VI):

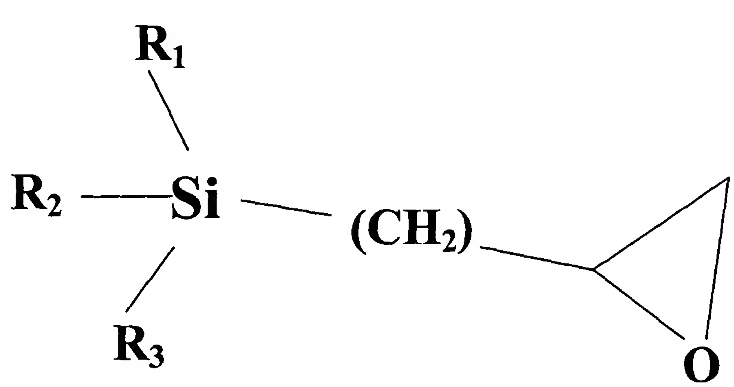


(VI)

wherein:

each of R_1 and R_2 is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl.

[0021] A further sub-class of silyloxirane compounds within the general formula (I) has the formula (VII):

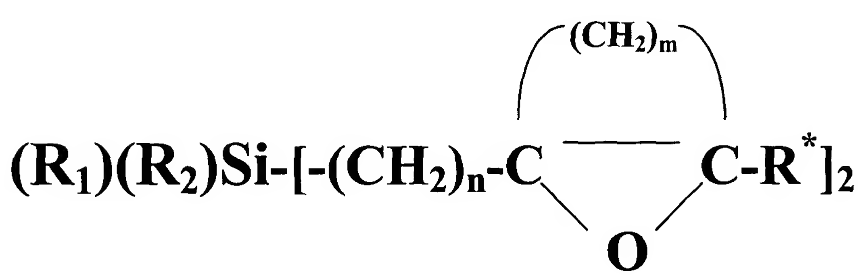


(VII)

wherein:

each of R_1, R_2 and R_3 is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl.

[0022] A further sub-class of compounds within the scope of broad formula (I) comprises compounds of the formula (VIII) set out below:



(VIII)

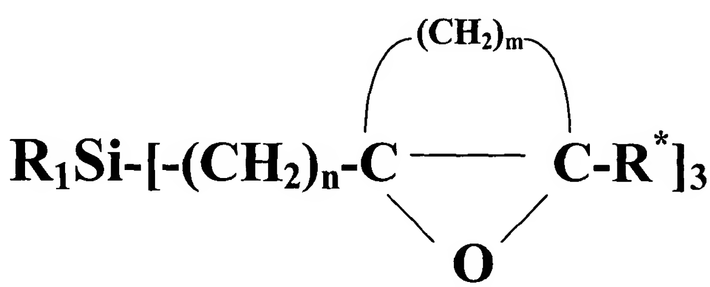
wherein:

m is an integer having a value of from 0 to 6 inclusive;

n is 0 or 1;

each R_1, R_2 and R^* can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl.

[0023] A further sub-class of oxiranyl compounds of the invention has the formula (IX):



(IX)

wherein:

m is an integer having a value of from 0 to 6 inclusive;

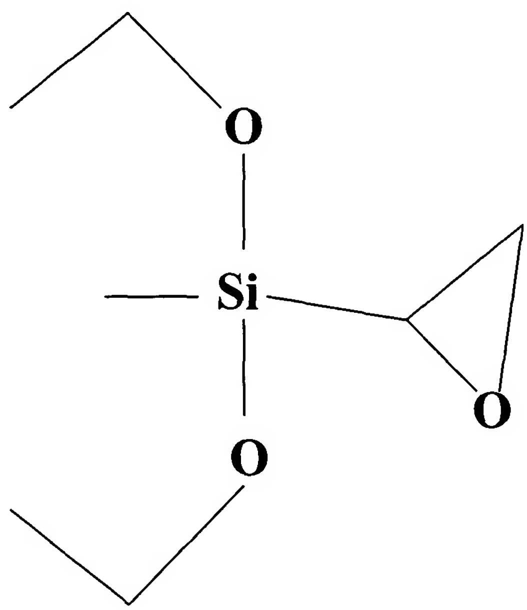
n is 0 or 1;

each of R_1 and R^* can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl,

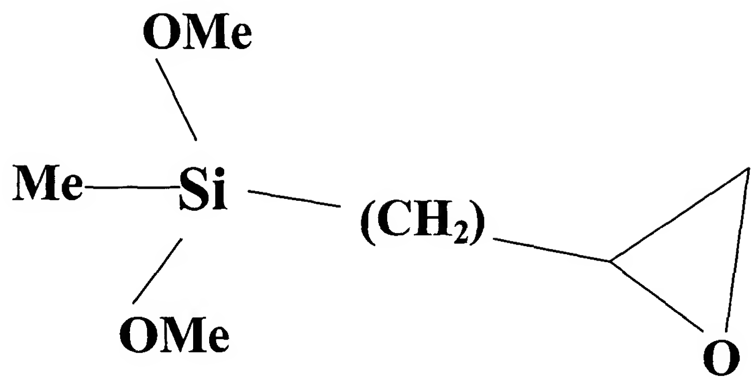
C_1-C_8 alkoxy, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, and C_3-C_6 allyl.

[0024] Illustrative compounds within the broad scope of the present invention include the compounds set out below.

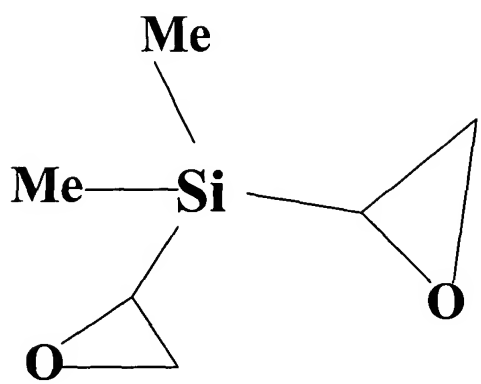
[0025] Formula (A), $Me(EtO)_2SiCHCH_2O$:



[0026] Formula (B), $Me(MeO)_2Si\ CH_2CHCH_2O$:



[0027] Formula (C), $Me_2Si\ (CHCH_2O)_2$:



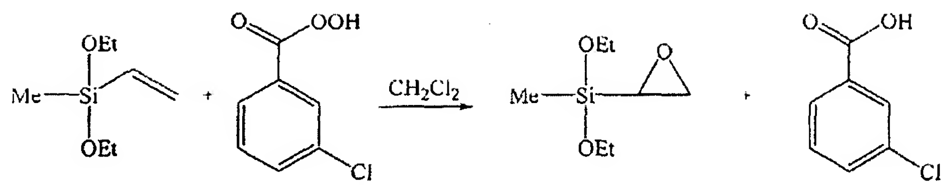
wherein Me is methyl.

[0028] The ethyleneoxide-substituted silane compounds of the invention are useful precursors for the formation of low k films having dielectric constant below 2.5, by deposition methods such as plasma-enhanced chemical vapor deposition (PECVD). The

ethyleneoxide moiety in the precursor molecule provides a functionality with a weak carbon-oxygen bond. Under mild plasma conditions, this bond breaks first and by absorbing the plasma energy prevents the breakage of other silicon-carbon bonds in the precursor molecule. The resulting incorporation of carbon in the deposited films provides lowered k values. The formation of oxygen and carbon radicals during the PECVD film-forming process also facilitates cross-linking within the film to produce films of superior hardness.

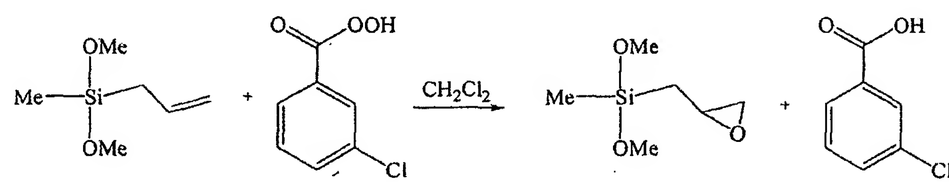
[0029] The ethyleneoxide-substituted silane precursor compounds of the invention are readily synthesized by oxidation of either vinyl or allyl groups on correspondingly functionalized silane compounds. Useful oxidizing agents for such purpose include meta-$Cl(C_6H_4)C(O)OOH$, denoted m-CPBA, ^tBuOOH, wherein ^tBu is tertiary butyl, and $Me_3OOSiMe_3$, wherein Me is methyl, as well as other oxidants having sufficient oxidizing strength and inertness in relation to Si-OR fragments. The reaction can be run in a suitable non-flammable solvent medium, e.g., using a solvent such as dichloromethane (CH_2Cl_2), chloroform ($CHCl_3$), etc., which provides a safe environment for the strong oxidizing agent.

[0030] An illustrative example is the synthesis of $Me(EtO)_2SiCHCH_2O$, which is obtained in 50% yield according to Reaction (1) below.



(1)

[0031] Another illustrative example is the synthesis of $Me(MeO)_2SiCH_2CHCH_2O$, which is obtained in almost quantitative yield according to Reaction (2) below.

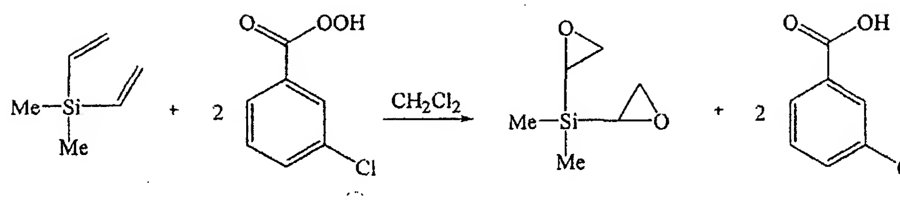


(2)

[0032] Reaction (2) involving the allylsilane analog was much faster compared to Reaction (1) involving the corresponding vinyl compound.

[0033] $Me(EtO)_2SiCHCH_2O$ was employed as a precursor for PECVD formation of low k films, and yielded films having a k value of 3.1 and a hardness of 2.3 GPa.

[0034] Very low k value films can be obtained using the dioxiranylsilane compounds of formula (III) above, such as $Me_2Si(CHCH_2O)_2$, which can be synthesized according to Reaction (3) below.



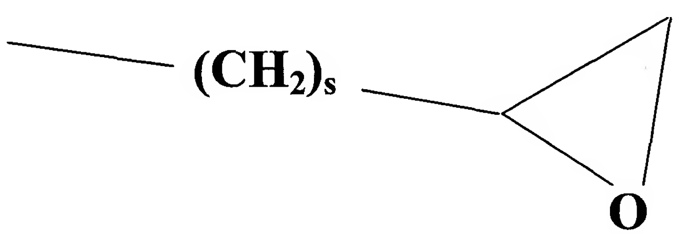
(3)

[0035] The precursor compounds of the invention in a second general category are bridged silane source reagents of the formula (III):

$$R^4R^5R^6Si\text{-}(CH_2)_y\text{-}SiR^7R^8R^9 \qquad \text{(III)}$$

wherein:

each of R^4, R^5, R^6, R^7, R^8 and R^9 can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 fluoroalkyl, C_1-C_8 alkoxyl, C_6-C_{10} cycloalkyl, C_6-C_{10} aryl, C_6-C_{10} fluoroaryl, C_2-C_6 vinyl, C_3-C_6 allyl, and oxiranylalkylene of formula (IV)



(IV)

wherein s is 0 or 1; and

y is an integer having a value of from 0 to 4 inclusive.

[0036] Preferably, the number of methylene groups, i.e., $-(CH_2)-$ groups, in the silane compound of formula (III) is one or two.

[0037] The precursors of formula (III) employ bridged carbons between silicon atoms in the molecule, to improve film hardness. During deposition, the $-(CH_2)_x-$ moieties remain in the film's cross-linking silicon centers, to provide significantly improved hardness, and concurrently lower k values due to the incorporation of carbon in the deposited film, in relation to corresponding silane precursors lacking the $-(CH_2)_x-$ moieties of the formula (III) compounds.

[0038] The bridged silanes of formula (III) can be readily synthesized by derivatization of commercially available bridged chlorosilanes.

[0039] For example, $Me(MeO)_2SiCH_2CH_2SiMe(OMe)_2$ and $Me_2(MeO)SiCH_2CH_2SiMe_2(OMe)$ are readily synthesized at yields of 82% and 88%, respectively, by the respective Reactions (4) and (5) set out below.

Reaction (4):

$$MeCl_2SiCH_2CH_2SiMeCl_2 + 4MeONa \rightarrow Me(MeO)_2SiCH_2CH_2SiMe(OMe)_2 + 4NaCl$$

Reaction (5):

$Me_2ClSiCH_2CH_2SiMe_2Cl + 2MeONa \rightarrow Me_2(MeO)SiCH_2CH_2SiMe_2(OMe) + 2NaCl$

[0040] $(MeO)_3SiCH_2Si(OMe)_3$ is correspondingly synthesized using MeONa by the reaction scheme of Reaction (6) set out below.

Reaction (6):

$HSiCl_2CH_2HSiCl_2 + 4MeONa + 2MeOH \rightarrow (MeO)_3SiCH_2Si(OMe)_3 + 4NaCl + 2H_2$

[0041] The compounds of formula (III) can be used as precursors for formation of low k, high strength films, in vapor deposition processes.

[0042] Such precursors of formula (III) can be employed alone or alternatively in combination with porogen materials, such as porogens of the formula (X):

$$R^{10} R^{11} Si R^{12} R^{13} \qquad \text{(X)}$$

wherein:

each of R^{10}, R^{11}, R^{12} and R^{13} can be the same as or different from one another and each is independently selected from the group consisting of H, C_1-C_8 alkyl, C_1-C_8 alkoxyl, C_6-C_{10} cycloalkyl, and C_6-C_{10} aryl, with the proviso that at least one of R^{10}, R^{11}, R^{12} and R^{13} is C_1-C_8 alkoxyl.

[0043] Preferred porogens include:

$^{t}Bu_2Si(OCH_3)_2$

$^{t}Bu_2Si(OC_2H_5)_2$

$(C_6H_5)_2Si(OCH_3)_2$

$(C_6H_5)_2Si(OC_2H_5)_2$

$(C_6H_{11})_2Si(OCH_3)_2$

$(C_6H_{11})_2Si(OC_2H_5)_2$

$^{t}BuSi(OCH_3)_2H$

$^{t}BuSi(OC_2H_5)_2H$

$(C_6H_5)Si(OCH_3)_2H$

$(C_6H_5)Si(OC_2H_5)_2H$

$(C_6H_{11})Si(OCH_3)_2H$

$(C_6H_{11})Si(OC_2H_5)_2H$

$(^{t}Bu)(CH_3)Si(OCH_3)_2$

$(^{t}Bu)(CH_3)Si(OC_2H_5)_2$

$(C_6H_5)(CH_3)Si(OCH_3)_2$

$(C_6H_5)(CH_3)Si(OC_2H_5)_2$

$(C_6H_{11})(CH_3)Si(OCH_3)_2$

$(C_6H_{11})(CH_3)Si(OC_2H_5)_2$

and the like, wherein ^tBu is tertiary butyl.

[0044] It is also within the purview of the present invention to employ the organosilicon precursors of the invention, e.g., of Formula (I) and/or Formula (III), in combination with other organosilicon precursor compounds, such as TMCTS or other, e.g., cyclosiloxane, precursor(s), to provide improvement in the film properties that would otherwise be obtained using such other organosilicon precursor compounds in the absence of the organosilicon precursors of the invention.

[0045] It will be appreciated that the foregoing is illustrative of a wide variety of oxiranylsilane compounds and bridged silane compounds that can be synthesized within the general scope of the present invention and usefully employed to form low k, high strength films by vapor deposition methods.

[0046] The features and advantages of the invention are more fully shown with reference to the following non-limiting examples.

[0047] Example 1 – Synthesis of $Me(EtO_2)SiCHCH_2O$

[0048] m-CPBA (14 g, 62.47 mmol based on 77% purity) was dried in vacuum until vacuum reached 10 mTorr. Anhydrous methylene chloride (100 mL) was added to

dissolve m-CPBA. $Me(EtO)_2SiCH{=}CH_2$ (10 g, 62.5 mmol) was added to the clear solution of m-CPBA in CH_2Cl_2. No visual changes immediately occurred. The white precipitate of m-ClC_6H_4COOH formed within 2 hours. The reaction mixture was reduced in volume under vacuum (about 75 mL of CH_2Cl_2 were removed). Pentane (50 mL) was added and then the mixture was filtered. Low boiling point volatiles were removed in vacuum. The mixture of unreacted $Me(EtO)_2SiCH{=}CH_2$ (10%) and the product (90%) was isolated under vacuum distillation. Second distillation yielded high purity oxirane. Yield: 50%. Boiling point: 30°C at 0.2 Torr. Mass spectrum: (EI, %): m/z 176 (M^+, 1), 161 (M^+-Me, 10), 133 (M^+-$CHCH_2O$, 100). ^1H NMR (C_6D_6): δ 3.76-3.64 (m, 4H, $SiOC\underline{H}_2CH_3$), 2.59-2.5 (m, 2H, $SiCHC\underline{H}_2$), 2.08-2.05 (m, 1H, $SiC\underline{H}CH_2$), 1.17-1.07 (m, 6H, $SiOCH_2C\underline{H}_3$), 0.07 (s, 3H, $SiC\underline{H}_3$). ^{13}C NMR: (C_6D_6) δ 59.15 ($SiO\underline{C}H_2CH_3$), 44.07 ($Si\underline{C}HCH_2$), 18.91 ($SiOCH_2\underline{C}H_3$), -6.25 ($Si\underline{C}H_3$).

[0049] Example 2 – Synthesis of $Me(MeO)_2SiCH_2CHCH_2O$

[0050] m-CPBA (7.66 g, 34.18 mmol based on 77% purity) was dried in vacuum at room temperature until vacuum reached 10 mTorr. Anhydrous methylene chloride (60 mL) was added to dissolve m-CPBA. $Me(MeO)_2SiCH{=}CH_2$ (5 g, 34.18 mmol) was added to the solution of m-CPBA in CH_2Cl_2. The immediate reaction was evidenced by moderate heat generation. White precipitate of m-ClC_6H_4COOH formed within 1 hour. The reaction mixture was left overnight. Next morning, the reaction mixture was reduced in volume under vacuum. Pentane (50 mL) was added and then the mixture was filtered. Low boiling point volatiles were removed in vacuum. The product was obtained by vacuum distillation. Yield: 40%. Boiling point: 30°C at 0.2 Torr. Mass spectrum: (EI,

%): m/z 162 (M^+, 1), 174 (M^+-Me, 10), 105 (M^+-CH_2CHCH_2O, 100). ^1H NMR (C_6D_6): δ 3.31 (s, 3H, $SiOC\underline{H}_3$), 3.30 (s, 3H, $SiOC\underline{H}_3$), 2.9-2.82 (m, 1H, $SiCH_2C\underline{H}CH_2O$), 2.44-2.41 (m, 1H, $SiCH_2CHC\underline{H}HO$), 2.18-2.15 (m, 1H, $SiCH_2CHCH\underline{H}O$), 1.09-1.02 (m, 1H, $SiC\underline{H}HCHCH_2O$), 0.73-0.65 (m, 1H, $SiCH\underline{H}CHCH_2O$), 0.08 (s, 3H, $SiC\underline{H}_3$). ^{13}C NMR: (C_6D_6) δ 50.30 ($SiO\underline{C}H_3$), 50.28 ($SiO\underline{C}H_3$), 48.94 ($SiCH_2\underline{C}HCH_2O$), 48.36 ($SiCH_2CH\underline{C}H_2O$), 18.83 ($Si\underline{C}H_2CHCH_2O$), -4.30 ($Si\underline{C}H_3$).

[0051] Example 3 – Synthesis of $Me_2Si\ (CHCH_2O)_2$

[0052] m-CPBA (8 g, 35.70 mmol based on 77% purity) was dried in vacuum until vacuum reached 10 mTorr. Anhydrous methylene chloride (100 mL) was added to dissolve m-CPBA. The solution of $Me_2Si(CH=CH_2)_2$ (2 g, 17.86 mmol) in CH_2Cl_2 was added to the clear solution of m-CPBA in CH_2Cl_2. No visual changes occurred. The reaction mixture was left stirring overnight. White precipitate of m-ClC_6H_4COOH formed by next morning. The mixture was reduced in volume under vacuum (about 80 mL of CH_2Cl_2 were removed). Pentane (50 mL) was added and then the mixture was filtered. Low boiling point volatiles were removed in vacuum. The mixture of $Me_2Si(CH=CH_2)(CHCH_2O)$ (15%) and the product (85%) was isolated using nitrogen trap under high vacuum. Yield: 50%. Boiling point: 45°C at 0.2 Torr. Mass spectrum: (EI, %): m/z 101 ($M^{+\,-}$ $CHCH_2O$, 20), 59 (Me_2SiH, 100). ^1H NMR (C_6D_6): δ 2.58-2.54 (m, 2H, $SiCHC\underline{H}HO$), 2.38-2.28 (m, 2H, $SiCHCH\underline{H}O$), 2.04-1.98 (m, 2H, $SiC\underline{H}CH_2O$), -0.10 and –0.12 (m, 6H, $SiC\underline{H}_3$). ^{13}C NMR: (C_6D_6) δ 44.27 and 44.19 ($SiCH\underline{C}H_2O$), 41.70 and 41.43 ($Si\underline{C}HCH_2O$), -7.36, -7.50 and –7.74 ($Si\underline{C}H_3$). The complicated NMR

spectra are consistent with four stereoisomerisms possible for $Me_2Si(C^*HCH_2O)_2$. Two diastereomers in the ratio of 1:1 were separated by GC/MS.

[0053] Example 4 – Synthesis of $[Me(MeO)_2SiCH_2]_2$

[0054] A solution of $[MeCl_2SiCH_2]_2$ (102.7 g, 0.4 mol) in tetrahydrofuran (THF) (500 mL) was added dropwise to 25 weight % solution of MeONa in MeOH (349 g, 1.6 mol, 1% excess) at room temperature. White precipitate formed almost immediately. The reaction mixture was stirred for 1 hour to ensure the complete substitution. Upon filtration, all volatiles were removed in vacuum to form a yellowish solution of MeONa in $[Me(MeO)_2SiCH_2]_2$. Pure $[Me(MeO)_2SiCH_2]_2$ was obtained by vacuum distillation. Yield: 82%. Boiling point: 55°C at 0.3 Torr. Mass spectrum: (EI, %): m/z 238 (M^+, 5), 223 (M^+ - Me, 15). ^1H NMR (C_6D_6): δ 3.37 (s, 12H, $OC\underline{H}_3$), 0.72 (s, 4H, $\underline{H}_2C-C\underline{H}_2$), 0.09 (s, 6H, $SiC\underline{H}_3$). ^{13}C NMR: (C_6D_6) δ 50.30 ($O\underline{C}H_3$), 4.98 ($H_2\underline{C}-\underline{C}H_2$), -5.99 ($Si\underline{C}H_3$).

[0055] Example 5 – Synthesis of $[Me_2(MeO)SiCH_2]_2$

[0056] A solution of $[Me_2ClSiCH_2]_2$ (100 g, 0.465 mol) in tetrahydrofuran (THF) (500 mL) was added dropwise to 25 weight % solution of MeONa in MeOH (200.68 g, 0.929 mol) at room temperature. White precipitate formed almost immediately. The reaction mixture was stirred for 1 hour to ensure the complete substitution. Upon filtration, all volatiles were removed in vacuum. Pure $[Me_2(MeO)SiCH_2]_2$ was obtained by vacuum distillation. Yield: 88%. Boiling point: 40°C at 0.3 Torr. Mass spectrum: (EI, %): m/z 206 (M^+, 5), 191 (M^+ - Me, 20), 89 (Me_2SiOMe, 100). ^1H NMR (C_6D_6): δ 3.29 (s, 6H,

$OC\underline{H}_3$), 0.59 (s, 4H, $\underline{H}_2C-C\underline{H}_2$), 0.09 (s, 6H, $SiC\underline{H}_3$). ^{13}C NMR: (C_6D_6) δ 50.41 ($O\underline{C}H_3$), 7.92 ($H_2\underline{C}-\underline{C}H_2$), -2.76 ($Si\underline{C}H_3$).

[0057] Example 6 – Synthesis of $[(MeO)_3Si]_2CH_2$

[0058] A solution of $(Cl_2HSi)_2CH_2$ (23.21 g, 0.108 mol) in tetrahydrofuran (THF) (120 mL) was added dropwise to 25 weight % solution of MeONa in MeOH (93.71 g, 0.434 mol) at room temperature. White precipitate formed almost immediately. The reaction mixture was stirred for 1 hour to ensure the complete substitution. Upon filtration, all volatiles were removed in vacuum and the product was obtained by vacuum distillation. Yield: 60%. Boiling point: 53°C at 60 mTorr. Mass spectrum: (EI, %): m/z 256 (M^+, 20), 241 (M^+ - Me, 5), 224 [M^+ - OMe, 100). ^1H NMR (C_6D_6): δ 3.49 (s, 18H, $OC\underline{H}_3$), 0.08 (s, 2H, $C\underline{H}_2$). ^{13}C NMR: (C_6D_6) δ 50.69 ($O\underline{C}H_3$), -9.02 ($\underline{C}H_2$).

[0059] Example 7 – Films produced with diethoxy methyl oxiranyl silane (DEOMORS)

[0060] $Me(EtO_2)SiCHCH_2O$ was synthesized as in Example 1.

[0061] The $Me(EtO_2)SiCHCH_2O$ was employed to form a deposited film on a substrate by low pressure plasma-enhanced chemical vapor deposition, in which the deposition process was carried out under the process conditions listed in Table 1 below. The process was carried out in a deposition chamber to which vapor was introduced by a showerhead injection device to the wafer disposed on the wafer heater.

[0062] Table 1.

Deposition Parameter	Value
Syringe setpoint, %	20
Liquid flow, milliliters per minute	0.13
Substrate temperature, °C	370
Radio frequency power, watts	250
Pressure, torr	6.0
Spacing (showerhead to wafer heater distance), mils	460
Time, seconds	120
Carrier gas flow rate, sccm/minute	200
Carrier gas	carbon dioxide

[0063] The deposited film had the characteristics shown in Table 2 below.

[0064] Table 2.

Film property	Value

Dielectric constant, k	3.1
Indentation hardness, GigaPascals (GPa)	2.3
Indentation modulus, GigaPascals (GPa)	12.4
Deposition Rate, Angstroms/min	980

[0065] The film thus possessed an exceptional film hardness of 2.3 GPa with a dielectric constant k of 3.1. The film had less Si-H incorporation compared to films produced using precursors with large amounts of hydride, such as trimethylsilane and TMCTS. This is evidenced by the results in FIG. 1, which shows FTIR transmission spectra of a film deposited from TMCTS and a film deposited from $Me(EtO_2)SiCHCH_2O$ under low oxygen activity deposition conditions. The presence of large amounts of Si-H in the film is generally correlated with reduced mechanical strength in low k films, and the low Si-H content of the film deposited from $Me(EtO_2)SiCHCH_2O$ is consistent with the improvement achieved with the oxiranylsilane precursors of the present invention.

[0066] Films formed from oxiranylsilane precursors also demonstrate compatibility with low oxygen activity plasmas, which render such precursors compatible with oxygen sensitive porogens, e.g., organosilicon precursors containing t-butyl functional groups. The process conditions summarized in Table 1 reflect the fact that a small amount of CO_2 and the $Me(EtO_2)SiCHCH_2O$ precursor were the only potential sources of oxygen in the plasma. Under conditions similar to this, many hydride-containing precursors such as

TMCTS show a severely depressed deposition rate, and poor dielectric constant and hardness characteristics. Large amounts of Si-H are observed in films deposited from TMCTS. Si-H is not detected in films deposited under similar conditions using $Me(EtO_2)SiCHCH_2O$.

[0067] FIG. 2 is a plot of deposition rate, in Angstroms per minute, as a function of measured radio frequency power, in watts, for each of $Me(EtO_2)SiCHCH_2O$ (denoted in the graph as DEOMORS), tetramethylcyclotetrasiloxane (denoted in the graph as TMCTS), and tetraethylorthosilicate (denoted in the graph as TEOS), each utilized in the deposition process in combination with a same porogen under similar conditions.

[0068] As shown by the results of FIG. 2, $Me(EtO_2)SiCHCH_2O$ evidenced a markedly higher deposition rate in comparison with the prior art TEOS and TMCTS precursor materials.

[0069] Although the invention has been variously disclosed herein with reference to illustrative embodiments and features, it will be appreciated that the embodiments and features described hereinabove are not intended to limit the invention, and that other variations, modifications and other embodiments will suggest themselves to those of

ordinary skill in the art. The invention therefore is to be broadly construed, consistent with the claims hereafter set forth.